UNITED STATES DEPARTMENT OF AGRICULTURE

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Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

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FUMIGATION OF CITRUS PLANTS WITH HYDROCYANIC ACID: CONDITIONS INFLUENCING INJURY

By

R. S. WOGLUM, Entomologist, Tropical and Subtropical Fruit Insect Investigations

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By R. S. Woglum,[1] *Entomologist, Tropical and Subtropical Fruit Insect Investigations.*

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INTRODUCTION.

The important factors long known to modify damage to the fruit and foliage of citrus trees under orchard conditions of fumigation with hydrocyanic acid include temperature, moisture, light, and physiological condition of the plant. Of these, light appears to have more completely influenced the application of this gas than any other factor and early confined fumigation to a night practice. Coquillett (*3*),[2] the originator of orchard fumigation with hydrocyanic acid, found early in his studies that citrus trees were less liable to injury by this gas when treated at night than in daytime, and explained that this result was due to decomposition of the gas by light and heat into other gases more injurious to the plants. Gossard (*7*), working with citrus trees in Florida, stated that "midday fumigation can hardly be practiced." More recently Fernald, Tower, and Hooker (*5*), experimenting with cucumbers and tomatoes under glass, concluded that for such tender plants day fumigation, even in cloudy weather, is unsafe.

Literature treating of the causes of fumigation injury is confined almost exclusively to the consideration of conditions, physiological

[1] Resigned September 11, 1920. [2] Reference is made by number (italic) to "Literature cited," p. 42.

as well as environmental, which prevail during the actual exposure of plants to the gas. The prefumigation and postfumigation environments have been given scant attention. The writer early in his fumigation studies observed types of injury not fully explainable by influences during the gas exposure, and subsequently it developed that certain factors must be considered, not only during but also before and after the gas treatment. Accordingly, a series of experiments was performed to determine the prefumigation and postfumigation influence, if any, of the two very important factors, heat and light. This paper presents the results of these experiments, and furthermore interprets the results in the light of field experience. In the discussion it has been found necessary to touch on other factors which also bear on the subject of fumigation injury.

THE EFFECT OF HYDROCYANIC ACID ON PLANTS.

The modification of plant injury by most external factors can be ascertained with sufficient accuracy and comprehensiveness to guide field work without attempting to determine the actual physiological action which occurs within the plant tissues when these are exposed to varying concentrations of hydrocyanic acid. Studies of the effect of this gas on plant metabolism have been made, however, and some very important papers have appeared setting forth the results of careful research on this subject. One of the earliest comprehensive papers confined to this subject was issued by Schroeder (*17*), in which he concluded, as the result of a long series of determinations on the effect of potassium cyanid on the fungus *Aspergillus niger*, that injury arises through paralysis of respiration, but that the reduced respiration is followed by complete recovery when the poison period does not last too long. Moore and Willaman (*12*), working with greenhouse plants, similarly conclude that the absorption of more or less hydrocyanic acid by plants results in a reduction of respiratory activity, and show that this inhibitory effect on respiration is due primarily to disturbance of the respiratory enzymes, oxidases, and catalase. Various other physiological effects resulting are the inhibition of photosynthesis and translocation of carbohydrates; also an increase in the permeability of the leaf septa.

Since the passage of gases takes place between the open air and the intercellular spaces of leaves through the stomata, it has been believed by most investigators of fumigation that hydrocyanic acid gains entrance into the tissues of fumigated plants through these openings. Researches by Moore (*11*) led to the conclusion that during fumigation hydrocyanic acid not only does enter plants through the stomata, if they are open, but also through the cuticle, depending upon its thickness and degree of cutinization. In a recent paper Clayton (*1*) emphasizes that the stomata seem to be the most important single factor in determining the amount of injury resulting from

hydrocyanic acid fumigation, although Stone (*18*) concluded from his investigations that susceptibility to injury is due more to the condition of the tissue, whether thin and tender or resistant, than to the open or closed condition of the stomata.

It has not been uncommon in California to hear practical fumigators state that plant injury during fumigation is due to impurities in the cyanid or sulphuric acid. One writer (*23*) has attributed injury to sulphuric-acid fumes given off during the gas generation and has discussed in great detail how such action is brought about. The work of Schroeder, Moore, and others disproves any conclusion that does not mention the cyanid gas itself as the cause of plant injury, and experiments by the writer (*19*) furnish further data in disproving these theories with reference to sulphuric acid. Furthermore, the recent wide use of high-purity liquid hydrocyanic acid, a material free of sulphuric acid, has been attended by the customary fruit and foliage injury.

DETAILS OF EXPERIMENTS.

Boxed seedling orange trees, pruned to several branches and from 1 to 2 feet in height, were grown beneath a canvas shelter which afforded protection from the midday sun. The foliage was dense and for the most part consisted of heavily cutinized leaves, except for the tender growth toward the top.

The gas-tight fumigatorium (Pl. I, A) in which the experiments were performed contained 100 cubic feet of space and was equipped with two large glass windows, which permitted the regulation of light conditions. Treatment in the shade signifies that both windows were fully exposed to diffused light. The temperature of the fumigatorium for any one experiment was uniform during the exposure, unless otherwise noted. All records were made in the Fahrenheit scale. Only high-grade commercial cyanids of 96 to 99 per cent purity were used. Potassium cyanid was used according to the 1–1–3 formula, or sodium cyanid according to the 1–1½–2 formula (*19*). The foliage in all cases was dry, unless otherwise noted. Check plants were used in all experiments and failure to refer to them signifies that the checks were in no way injured. The dosages in these experiments approximate those employed in orchard treatment in California. All plants in any one experiment were fumigated at the same time. Immediately after treatment they were removed from the fumigatorium and placed in different environments of temperature and light. Final notes on results were taken five to seven days after treatment. Shade signifies protection from the sun by a canvas shelter or a wooden building. Darkness means total exclusion of light. Moisture does not include atmospheric humidity. Injury as included in this paper should be interpreted as meaning damage to or death of tissues, so

that the effect is observable to the naked eye. Burned signifies severe injury amounting to the partial or total discoloration of numerous leaves, as by heat. Singed indicates slight burning, especially at the tips or edges of leaves.

Varying degrees of damage to the plants were indicated as follows in all experiments:

0—Plants entirely unaffected externally.

1—Some of the tenderest undeveloped leaves or tips of tender shoots at least slightly injured.

2—Tenderest tips with undeveloped leaves severely injured; fully grown tender leaves sometimes slightly affected; mature leaves uninjured.

3—Tender growth, including fully developed new leaves, destroyed; old leaves slightly affected.

4—Mature leaves in large numbers severely burned.

5—One-half to entire plant severely burned.

THE EFFECT ON PLANT INJURY OF TEMPERATURE, LIGHT, AND MOISTURE BEFORE FUMIGATION.

The fumigation of growing plants is usually conducted without regard to their environment prior to the gas exposure, barring the factor moisture relative to which a divergence of opinion exists. The experimental evidence presented in this paper bearing on prefumigation conditions draws attention not only to the influence of moisture but also to that of temperature and light. Data on the influence of these factors are brought out in experiments 1 to 9, inclusive, as well as in 11, 12, 14, 15, and 18, these latter experiments being discussed under the subject of postfumigation influences. Certain of these experiments, namely, 1, 2, 12, 14, 15, and 18, are of special value by reason of the number of postfumigation environments also included in each experiment.

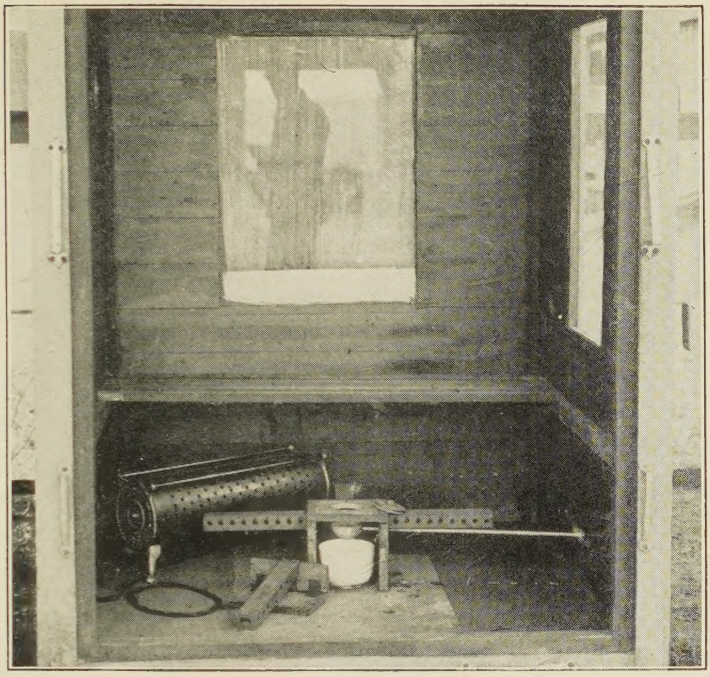
EXPERIMENT 1.

Condition during fumigation, shade, 58°–60° F.
Dosage, 1½ ounces KCN.
Date, March 18, 1915, 8.45–9.45 a. m.
Plants in each test, 2; total, 30.
Remarks: Plants somewhat hardened.

Results.

Condition after fumigation.	Condition before fumigation.		
	Dark, 60° F.	Shade, 58° F.	Sun, 68° F.[1]
Dark, 60° F.	1	1	3
Shade, 58° F.	1	1	3
Dark, 86° F.	2+	2+	5
Shade, 90° F.	2+	2+	5
Sun, 72° F.	3+	3+	5

[1] Plants in sunshine for 2 or 3 hours before fumigation. Maximum sun temperature for day, 77° F.



FUMIGATION OF CITRUS PLANTS WITH HYDROCYANIC ACID.

A, Fumigatorium used in experimental work, showing interior arrangement. *B*, Orchard citrus tree fumigated in the daytime and immediately afterward exposed to a hot sunshine; foliage completely destroyed. Other trees in the same grove, fumigated at an equal temperature but free from sunshine influence, were uninjured.

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EXPERIMENT 2.

Condition during fumigation, shade, 67°–69° F.
Dosage, 1¼ ounces KCN.
Date, March 15, 1915, 9.30–10.30 a. m.
Plants in each test, 2; total, 18.
Remarks: Plants somewhat hardened.

Results.

Condition after fumigation.	Condition before fumigation.		
	Dark, 55° F.	Shade, 67° F.	Sun, 75° F.
Dark, 55° F.[1]	1	1	3
Shade, 70° F.[2]	1	1	3
Sun, 75° F.[3]	2+	2+	5

[1] Temperature 55°–57° F. throughout day.
[2] Maximum shade temperature during day, 80° F., at 1.30 p. m.
[3] Maximum sun temperature during day, 86° F., at 1.30 p. m.

EXPERIMENT 3.

Condition during fumigation, shade, 57°–58° F.
Condition after fumigation, shade, 59°–66° F., for 24-hour period.
Dosage, 1 ounce NaCN.
Date, September 28, 1915, 7.10–7.50 a. m.
Plants in each test, 5; total, 15.

Results.

Condition before fumigation.		
Shade, 56° F.[1]	Shade, 90° F.[2]	Sun, 60° F.[3]
2	2	2

[1] At cool temperature several hours before fumigation.
[2] At temperature 88°–90° F. for 1 hour before fumigation; previously at 56° F.
[3] In sun for 1¼ hours before fumigation.

EXPERIMENT 4.

Condition during fumigation, shade, 63° F.
Condition after fumigation, shade, 88°–90° F.
Dosage, 1 ounce NaCN.
Date, September 28, 1915, 9–9.40 a. m.
Plants in each test, 3; total, 12.

Results.

Condition before fumigation.			
Shade, 67° F., plants wet.[1]	Shade, 67° F., plants dry.	Sun, 72° F., plants wet.[1]	Sun, 72° F. plants dry.
3	3	3	4

[1] Plants thoroughly sprinkled with tap water before fumigation.

EXPERIMENT 5.

Condition during fumigation, dark, 64°–66° F.
Condition after fumigation, dark, 60° F.
Dosage, 1¼ ounces KCN.
Date, May 17, 1916, 6.07–6.57 a. m.
Plants in each test, 7; total, 14.

Results.

Condition before fumigation.	
Dark, 64°–66° F.	Dark, 90°–102° F.[1]
2	2

[1] 5 hours before fumigation temperature raised from 70° to 90°–102° F.

EXPERIMENT 6.

Condition during fumigation, dark, 60° F.
Condition after fumigation, shade, 64° F.
Dosage, 1¼ ounces KCN.
Date, March 30, 1916, 9.37–10.27 a. m.
Plants in each test, 5; total, 15.

Results.

Condition before fumigation.		
Sun, 67° F., plants dry.	Sun, 67° F., plants wet, water temperature, 58° F.	Sun, 67° F., plants wet, water temperature, 86° F.
1	1	1

EXPERIMENT 7.

Condition during fumigation, dark, 72°–73° F.
Condition after fumigation, shade, 65° F.
Dosage, 1 ounce NaCN.
Date, October 7, 1915, 12.10–12.50 p. m.
Plants in each test, 5; total, 15.
Remarks: Plants exposed to the sunshine for several hours, then wet thoroughly immediately before fumigation.

Results.

Condition before fumigation.		
Sun, 80° F., plants dry.	Sun, 80° F., plants wet, water temperature, 64° F.	Sun, 80° F., plants wet, water temperature, 96° F.
4	3	4

All dry plants had the mature foliage quite severely burned, while only 3 of the 5 hot-water-treated plants were equally severely affected. None of the plants treated with cold water were as severely injured as where dry.

EXPERIMENT 8.

Condition during fumigation, dark, 62° F.
Condition after fumigation, shade, 67° F.
Dosage, 1¼ ounces KCN.
Date, May 17, 1916, 9.50–10.40 a. m.
Plants in each test, 5; total, 15.

Results.

Condition before fumigation.		
Shade, 65° F., plants dry.	Shade, 65° F., plants wet, water temperature, 68° F.	Shade, 65° F., plants wet, water temperature, 100° F.
2	2	2

EXPERIMENT 9.

Condition during fumigation, dark, 62° F.
Condition after fumigation, sunshine, 74° F.
Dosage, 1¼ ounces KCN.
Date, March 30, 1916, 10.57–11.47 a. m.
Plants in each test, 5; total, 10.

Results.

Condition before fumigation.	
Shade, 66° F., dry.	Shade, 66° F., wet.
4	4

DARKNESS AND SHADE.

In experiment 1 ten citrus plants in the dark at a temperature of 60° F. and ten in the shade at approximately the same temperature (58° F.) were fumigated at the same time. After treatment they were so divided that plants from each prefumigation condition were placed under five distinct postfumigation environments, each to include two plants from the darkness and two from the shade. No difference in degree of injury could be detected between the plants from prefumigation shade and those from prefumigation darkness in any of the five postfumigation conditions. Equivalent results are presented in experiment 12 between the series of plants in prefumigation shade and prefumigation darkness at 60° F. These results would appear to indicate that neither darkness nor diffused light before fumigation in any way influences the degree of injury to citrus plants from treatment with hydrocyanic acid.

TEMPERATURE.

The relation of temperature before fumigation to plant injury is brought out in experiments 2, 3, 5, 14, 15, and 18. In experiment 3 it is seen that plants at a shade temperature of 90° F. before fumigation were no more severely injured than others at a temperature of 56° F. Practically identical results occurred in experiment 5, where the prefumigation conditions were darkness at temperatures of 64°–66° F. and 90°–102° F., and in both cases merely the tenderest growth was slightly injured. Experiments 3 and 5 were performed at cool temperatures, and the postfumigation environment was cool. On the other hand, experiment 15, which was conducted at the high temperatures of 86°–91° F., developed no difference in injury between plants at prefumigation temperatures of 62° and 90° F.

In experiments 14 and 18 most of the plants showed no apparent difference in injury attributable to temperature before exposure. A few plants, however, did show slightly greater injury than others under similar postfumigation conditions and in these cases all the more severely injured plants were under the highest prefumigation temperatures (80° and 76° F., respectively). These two experiments were performed at comparatively high temperatures (85° to 92° F.).

It would appear from these experiments, therefore, that where plants are in shade or darkness the temperature immediately previous to fumigation has little influence on the resultant plant injury. Sometimes, however, a difference in plant injury apparently due to heat influences develops, and in such cases the greatest injury appears on those plants subject to the highest prefumigation temperatures. In the experiments in this paper the prefumigation temperatures ranged between 56° and 102° F. Within these limits there was little or no difference in injury where the fumigation and postfumigation temperatures were both below 70° F. However, slightly more increased injury did occur at the prefumigation temperatures of 76° and 80° F. than at 56° F. in two experiments in which the actual fumigation temperature was about 85° F. This would indicate the advisability of keeping plants at a cool temperature prior to fumigation in case the fumigation and postfumigation environments are hot. If the fumigation and postfumigation temperatures are cool a comparatively high prefumigation temperature appears to have little more effect on the results than a cool temperature.

SUNSHINE.

The influence of sunshine on plants before fumigation is shown by the results of experiments 1 to 4, 12, 14, 15, and 18. In experiment 1 this influence previous to the gas treatment contrasts sharply with that of diffused light or darkness. Sun and shade exposed plants under cool temperature conditions were fumigated at the same time and on removal from the fumigatorium were placed under five dif-

ferent conditions. In each of the five conditions the prefumigation sun-exposed plants developed decidedly greater injury than those that were in shade before treatment. The results of experiment 18, in which plants were exposed to a hot sunshine (83° F.) immediately before fumigation and fumigated at a high temperature, show all sun-exposed plants killed regardless of the postfumigation conditions; yet others in the shade at approximately the same prefumigation temperature (76° F.) and placed at a temperature of 56° F. after the treatment had only the very tenderest foliage singed. The effect of prefumigation sunshine is not so conclusively brought out in the other experiments, but, with the exception of No. 3, it appears to have intensified the injury in at least a few of the trees treated. Experiment 3 alone shows no difference between plants in the shade and those in the sunshine previous to fumigation. It is noted in this case that the sunshine temperature was 60° F. and the fumigation and postfumigation conditions were equally cool, all three being ideal for exposure to cyanid gas.

A comparative study of the temperature before and after treatment shows that the effect of prefumigation sunshine is modified by the degree of heat present at these different times. For instance, in experiment 3 where the sunshine appeared not to affect the degree of injury more than the shade, all fumigation conditions, the prefumigation, postfumigation, and actual fumigation, approximated 60° F. On the other hand, experiment 2, which was performed with the same type of plants, the same dosage, and at approximately the same temperature, exhibited a decided difference in injury between the prefumigation shade and sunshine-exposed plants, the injury in the latter being greater than for experiment 3. It is noted that the sun temperature in experiment 2 was 75° F., whereas in experiment 3 it was 60° F., which shows that the degree of injury attributable to sunshine increased with the increased temperature. Thus a hot sunshine before fumigation is more to be avoided than a cool sunshine.

In conclusion it can be stated that the experimental evidence in this paper appears to show that sunshine coming in contact with citrus plants before fumigation tends to produce greater injury than where plants are in the shade or darkness; that sunshine accompanied by a high temperature is more injurious than if accompanied by a low temperature; that the degree of injury is modified by the postfumigation conditions, greater injury developing at high temperatures than at low temperatures; that the most critical environment is to subject plants exposed to a hot sunshine before fumigation to a hot sunshine after fumigation; finally, that a high temperature during fumigation probably increases the injury of prefumigation sunshine-exposed plants over that taking place at a low temperature.

MOISTURE.

The effect of moisture on fumigated citrus trees is shown in experiments 4, 6 to 9, and 11, in which varied prefumigation conditions occur. In Nos. 4, 8, 9, and 11 a number of plants in the shade at temperatures between 60° and 68° F. were drenched with water before they were placed in the fumigatorium with others having perfectly dry foliage, and were then immediately subjected to hydrocyanic-acid gas. Thirty-seven plants in all were used in these four experiments and in no case was there any apparent difference in injury between the wet and the dry plants, even though a number of the trees had some very tender foliage.

In experiments 4, 6, and 7 plants were exposed to prefumigation sunshine at temperatures ranging from 67° to 80° F. Immediately before fumigation a part was drenched with water and afterwards fumigated with others having perfectly dry foliage. Experiment 6 exhibits the same degree of injury for the wet plants as for the dry, a condition which holds true whether the water used in the treatment was 58° or 86° F. In experiment 4 the dry plants were slightly more severely injured than the wet, quite the contrary to what would be expected, and in fact to what is shown by Moore (*11*) to take place in the case of tender greenhouse plants. In experiment 7 the dry plants were likewise more severely injured than those treated with cool water, although where wet with warm water the injury was equal. While these two experiments are insufficient in themselves to prove definitely that plants subjected to a hot sunshine before fumigation are more severely injured when dry than when wet it at least indicates that the wetting of such plants can, in some cases at least, reduce the degree of injury to an extent. In this connection it should be noted that the reduction of injury to the wet plants occurred where the water used was at a temperature considerably lower than that of the sunshine. Water at a temperature equal to or higher than the sun temperature did not appear to influence the degree of injury over that normal to dry plants.

In conclusion it may be stated that water on citrus plants appears in no way to affect the degree of injury, if the plants are subjected to shade or darkness before treatment; if, however, plants are in the direct sunshine before treatment, water appears to reduce the injury slightly, at least in some cases where the temperature of the water is below that of the sunshine.

THE EFFECT ON PLANT INJURY OF TEMPERATURE, LIGHT, AND MOISTURE AFTER FUMIGATION.

Fumigation with hydrocyanic acid is usually considered completed with the separation of the treated plants from exposure to the gas. Little or no attention has been given to the postfumigation environ-

ment. That this environment may modify the degree of plant injury is shown in the following experiments, which indicate the influence of different light intensities and of different temperatures on citrus plants immediately after fumigation with hydrocyanic acid. These experiments were performed, some in darkness and some in the shade, at temperatures ranging from 60° to 91° F. All plants in each experiment were fumigated at the same time, part being placed immediately after treatment in direct sunshine, part in the shade, and, excepting Nos. 11, 13, and 19, part in darkness. An effort was made in several experiments to have the shade temperature approximate that of the sunshine, thereby eliminating consideration of the heat factor and furnishing an exact basis for determining the influence of the sun's direct rays, a factor of special consideration. Most of the experiments also contain postfumigation environments of shade or darkness at decidedly cooler temperatures than those of sunshine, and thus furnish data for study of comparative temperature influences. Four experiments, Nos. 12, 14, 15, and 18, include plants under three different prefumigation environments, each set of which was subjected to either four or five different postfumigation conditions. Such experiments offer a wide range of data on the influence of various prefumigation as well as postfumigation factors.

EXPERIMENT 10.

Condition during fumigation, dark, 64° F.
Condition before fumigation, dark, 64° F.
Dosage, 1 ounce NaCN.
Date, September 22, 1915, 7–7.40 a. m.
Plants in each test, 4; total, 20.

Results.

Condition after fumigation.				
Dark, 65° F.[1]	Shade, 65° F.[1]	Dark, 79° F.[2]	Shade, 79° F.[2]	Sun, 79° F.[2]
2	2	2	2	4

[1] At cool temperatures throughout the day.
[2] At equal temperatures throughout the day. Maximum 102° F. at 2 p. m.

EXPERIMENT 11.

Condition during fumigation, dark, 61° F.
Condition before fumigation, shade, 61° F.
Dosage, 1 ounce KCN.
Date, June 17, 1914, 8.15–9 a. m.
Plants in each test, 3; total, 12.
Remarks: Condition of plants comparatively tender. All at equal temperatures throughout the day after fumigation. Maximum 83° F. at 2 p. m. Plants wet immediately before fumigation.

Results.

	Condition after fumigation.	
	Shade, 65° F.	Sun, 65° F.
Foliage drenched with water	2	4
Foliage dry	2	4

EXPERIMENT 12.

Condition during fumigation, dark, 64°–65° F.
Dosage, 1½ ounces KCN.
Date, March 18, 1915, 10.50–11.50 a. m.
Plants in each test, 2; total, 30.
Remarks: Fumigatorium contained ice to maintain a low temperature. This absorbed much gas.

Results.

Condition before fumigation.	Condition after fumigation.				
	Dark, 60° F.	Shade, 60° F.	Dark, 90° F.[1]	Shade, 88° F.[1]	Sun, 75° F.[2]
Dark, 60° F.	2	2	3	3	3
Shade, 60° F.	2	2	3	3	3
Sun, 73° F.	2	2	4	4	4

[1] Temperature maintained 4 hours after treatment.
[2] Maximum temperature for day, 77° F.

EXPERIMENT 13.

Condition during fumigation, dark 66°–68° F.
Condition before fumigation, shade, 66° F.
Dosage, 1 ounce NaCN.
Date, November 17, 1917, 9–10 a. m.
Plants in each test, 4; total, 12.
Remarks: Plant foliage tender.

Results.

Condition after fumigation.		
Shade, 68° F.	Shade, 79° F.[1]	Sun, 79° F.[1]
2	2	5

[1] At equal temperatures throughout the day. Maximum 98° F. at 2 p. m.

All foliage on plants in the sunshine was destroyed, while those in the shade exhibited injury only to the tenderest growth.

EXPERIMENT 14.

Condition during fumigation, dark, 91°–92° F.
Dosage, 1¼ ounces KCN.
Date, March 15, 1915, 1.30–2.30 p. m.
Plants in each test, 2; total, 22.
Remarks: Plants were in a somewhat resistant condition. Temperature of the fumigatorium 80° F. when plants entered, being raised immediately to 90°–91° F. before fumigation, and thus maintained throughout the exposure.

Results.

Condition before fumigation.	Condition after fumigation.			
	Dark, 56° F.[1]	Shade, 80° F.[2]	Shade, 90° F.[3]	Sun, 85° F.[4]
Dark, 56° F.	2	3	3+	
Shade, 80° F.	3	3+	3+	4
Sun, 86° F.	3	4	4	5

[1] Temperature uniform throughout day.
[2] Held at sun temperature.
[3] Temperature 85°–90° F. maintained for 3 hours after treatment.
[4] Temperature dropped to 75° F. 3 hours after exposure.

EXPERIMENT 15.

Condition during fumigation, dark, 86°–91° F.
Dosage, 1½ ounces KCN.
Date, March 18, 1915, 12.35–1.35 p. m.
Plants in each test, 2; total, 30.
Remarks: Growth as in experiment 14. Temperature of fumigatorium 73° F. when plants entered, being raised immediately to and maintained at 86°–91° F. during fumigation.

Results.

Condition before fumigation.	Condition after fumigation.				
	Dark, 63° F.[1]	Shade, 63° F.[1]	Dark, 91° F.[2]	Shade, 89° F.[2]	Sun, 77° F.[3]
Dark, 62° F.	3	3	4	4	4
Dark, 90° F.	3	3	4	4	4
Sun, 77° F.	4	4	4	4	4

[1] Maximum temperature for 24 hours after treatment, 65° F.
[2] Temperature 86°–91° F. maintained for 3 hours after treatment.
[3] Temperature 3 hours after treatment, 69° F. Slight haze developed during afternoon and at 4.45 p. m. completely obliterated the sun.

EXPERIMENT 16.

Condition during fumigation, shade, 61°–63° F.
Condition before fumigation, dark, 60° F.
Dosage, 1 ounce NaCN.
Date, September 22, 1915, 6.10–6.50 a. m.
Plants in each test, 4; total, 20.

Results.

Condition after fumigation.				
Dark, 65° F.[1]	Shade, 64° F.[1]	Dark, 73° F.[2]	Shade, 70° F.[2]	Sun 73° F.[2]
2	2	2	2	4

[1] At cool temperatures throughout day.
[2] At equal temperatures throughout the day; maximum 102° F. at 2 p. m.

EXPERIMENT 17.

Condition during fumigation, shade, 60°–62° F.
Condition before fumigation, dark, 64° F.
Dosage, 1 ounce NaCN.
Date, September 21, 1915, 6.50–7.35 a. m.
Plants in each test, 5; total, 20.

Results.

Condition after fumigation.			
Dark, 64° F.[1]	Dark, 80° F.[2]	Shade, 70° F.[3]	Sun, 71° F.[3]
2	2	2	4

[1] Temperature 64°–68° F. throughout the day.
[2] Temperature 80°–91° F. during the day.
[3] Temperatures equal throughout the day; maximum 94° F. at 1 p. m.

EXPERIMENT 18.

Condition during fumigation, shade, 85°–89° F.
Dosage, 1¼ ounces KCN.
Date, March 15, 1915, 11.20–12.20 p. m.
Plants in each test, 2; total, 24.
Remarks: Growth as in experiment 14. Plants placed in fumigatorium at temperature 70°–75° F. which was immediately raised to and maintained at 85°–89° F. during fumigation.

Results.

Condition before fumigation.	Condition after fumigation.			
	Dark, 56° F.[1]	Shade, 79° F.[2]	Shade, 90° F.[3]	Sun, 85° F.[4]
Dark, 56° F.....	2	3	3	4
Shade, 76° F.....	2	3	4	5
Sun, 83° F.....	5	5	5	5

[1] Temperature practically uniform for day following treatment.
[2] Maximum temperature, 80° F.
[3] Temperature, 90° F. maintained for 4 hours.
[4] Maximum temperature, 86° F. at 1.30 p. m.

EXPERIMENT 19.

Condition during fumigation, shade, 78°–80° F.
Condition before fumigation, shade, 76° F.
Dosage, 1¼ ounces NaCN.
Date, November 2, 1917, 9.20–10.20 a. m.
Plants in each test, 2; total, 6.
Remarks: Plants hardened from growth in open.

Results.

Condition after fumigation.		
Shade, 74° F.[1]	Shade, 87° F.[2]	Sun, 87° F.[2]
2	2	5

[1] Maximum temperature, 80° F. at 2 p. m.
[2] Maximum temperature, 93° F. at 1. p. m.

DARKNESS AND SHADE.

The effect on plant injury of shade and darkness after fumigation is well illustrated by experiments 10, 12, 15, and 16 which are arranged in Table I for comparison of these influences.

TABLE I.—*Comparative effects of diffused light and darkness on plants after fumigation with hydrocyanic acid.*

	Postfumigation temperatures.								
	Experiment 10.		Experiment 12.			Experiment 15.		Experiment 16.	
	65° F.	79° F.	60° F.[1]	88°–90° F.[2]		63° F.[2]	89°–91° F.[1]	64°–65° F.	70°–73° F.
Darkness	2	2	2	3	4	3	4	2	2
Shade	2	2	2	3	4	3	4	2	2

[1] Includes 3 fumigation conditions.
[2] Includes 2 fumigation conditions.

An examination of this table shows that in none of the several tests included is there any difference in injury between the plants placed in darkness and those placed in the shade following fumigation. This condition holds equally true at the minimum postfumigation temperature of 60° F. or the maximum of 91° F. for these experiments. Likewise this situation does not appear to be altered by the temperature of fumigation, for experiments 10, 12, and 16 were performed at 61°–64° F. while experiment 15 was carried on at 86°–91° F.

SUNSHINE.

The influence of sunshine on citrus plants immediately after fumigation is clearly developed in experiments 10 to 19. Eight of these 10 experiments show a decidedly greater injury to the plants placed in the sunshine after fumigation than to those placed in either the shade or darkness at equivalent temperatures. This condition is brought out in Table II.

TABLE II.—*Comparative degree of injury between plants placed in the sunshine and those placed in the shade or darkness following fumigation.*

	Postfumigation temperatures.										
	Exp. 10.	Exp. 11.	Exp. 13.	Exp. 14.[1]		Exp. 16.	Exp. 17.	Exp. 18.[2]			Exp. 19.
	79° F.	65° F.	79° F.	80° F.	85° F.	70°–73° F.	70°–71° F.	85°–90° F.			87° F.
Darkness	2					2					
Shade	2	2	2	3+	4	2	2	3	4	5	2
Sunshine	4	4	5	4	5	4	4	4	5	5	5

[1] Experiment consisting of two distinct parts. [2] Experiment consisting of three distinct parts.

An examination of this table shows that a dosage which slightly injures merely the tenderest growth of plants placed either in the shade or darkness after fumigation may result in severe burning of even the old, resistant leaves if the treated plants are exposed to sunlight (Pl. II, A), while in extreme cases complete defoliation follows, as happened in experiments 13 and 19. Increased injury due to sunshine was apparent even at as low a sun temperature as 65° F., which was the minimum experienced (experiment 11). The plants in this case were comparatively tender, and this condition naturally invited greater injury than would have been the case with more resistant foliage. A study of the data presented in these experiments would appear to indicate that, all other conditions being the same, injury increases more or less directly with the sun temperature. The plants in experiment 11 were somewhat tender yet the degree of injury in the case of those exposed to the sunshine (65° F.) was less than to the plants in a hardened condition in experiment 19, in which the postfumigation sunshine temperature was 87° F. In this latter experiment the hardened or resistant growth of plants placed in the sunshine was almost completely destroyed, although plants placed in the shade at the same temperature merely had the tenderest growth injured (Pl. II, A). This would indicate that sunshine at such a high temperature is more injurious than sunshine at a low temperature; in short, that the toxic action of hydrocyanic acid on fumigated plants subjected to sunshine increases with the sun's intensity.

Turning to experiment 12 it is seen that the sun-exposed plants were no more injured than those in the shade at a slightly higher temperature. It so happened that in this experiment the fumigatorium contained a piece of ice which had been used to maintain a low temperature prior to the treatment. This ice absorbed gas with the result that the strength of the gas was greatly reduced at the end of the hour's exposure. A conclusion to be deduced from this experiment is that plants exposed either to a strong gas for a short period or to a dilute gas for a longer period before being placed in the sunshine are much less injured by fumigation than plants exposed to a gas which maintains its proper strength throughout the period of an hour's exposure, as in the other nine experiments. Data in support of this statement are found elsewhere in this paper and, furthermore, are supported by other experiments performed by the author but not included in this article.

The relation of the temperature of fumigation to injury to plants subsequently exposed to sunshine is not well shown by the experimental data presented. Plants in experiments 10, 11, 13, 16, and 17 were fumigated at comparatively cool temperatures (60°–68° F.), yet the injury was about as severe to those plants subsequently placed in the sunshine as to those under similar postfumigation conditions

FUMIGATION OF CITRUS PLANTS WITH HYDROCYANIC ACID.

A, Comparative effect of hot sunshine and shade, after fumigation, on citrus plants with resistant foliage. Immediately following the treatment two plants were placed in direct sunlight and one in the shade, at 87° F., and held at parallel temperatures throughout the remainder of the day. It is noted that leaves in the sun-exposed plants have abscissed at the base of the blade. *B*, Citrus plants with tender foliage which were exposed immediately after fumigation to the sun or shade at 79° F. The plant in the shade had merely the tender tips injured. All leaves and petioles of the sun-exposed plants were completely burned and cling without abscission.

in experiments 14, 15, and 18, which were fumigated at temperatures ranging from 86° to 92° F. This would appear to indicate that the temperature of fumigation within the limits of those experiments, 60° and 92° F., has little if any modifying influence on the resulting degree of injury to plants subjected to the sunshine after treatment. It happens, however, that the prefumigation or postfumigation conditions in experiments 14, 15, and 18 were exactly comparable to those in none of the other experiments mentioned. Although section 1 of experiment 15 approximates experiment 10 as to prefumigation and postfumigation conditions, it is seen that the maximum sun temperature for the day in experiment 15 was 77° F., whereas in experiment 10 it was 102° F. Therefore, definite conclusions regarding the influence of the temperature of fumigation on plants subsequently placed in sunshine can not be drawn until there is further experimental evidence bearing on this subject.

The effect of postfumigation sunshine on plant injury appears to be modified to a certain degree by the prefumigation light condition. This is well shown by experiments 2 and 14, in which the damage to the plants under postfumigation sunshine is greater in the case of plants exposed to prefumigation sunshine than to plants in prefumigation shade at a comparable temperature. It is probable that the prefumigation temperature modifies to some degree the effect of postfumigation sunshine, but this point is not conclusively proved in this paper.

TEMPERATURE.

The importance of the temperature to which plants are subjected after fumigation as a factor bearing on plant injury is brought out by the experimental data presented in experiments 1, and 10 to 19. It is shown in experiment 12 that fumigated plants placed immediately after treatment under a shade temperature of 88° F. or a darkness temperature of 90° F. are slightly more injured than those placed at a temperature of 60° F. A like condition is presented in experiment 15 between postfumigation temperatures of 63° F. and 89° or 91° F. Experiments 1, 14, and 18 also show slightly increased injury due to higher postfumigation temperatures in the shade or darkness. On the other hand, each experiment of numbers 2, 10, 13, 16, and 17 shows the same degree of injury for plants subjected to different temperatures of shade and darkness following fumigation. An examination of the details of these experiments, however, brings out a significant difference between the two groups. In the set of experiments (2, 10, 13, 16, and 17) in which there was no apparent difference in injury due to the different postfumigation temperatures it is seen that the difference between the high and low temperatures in any one experiment varies from 9° in experiment 16 to a maximum of 16° in experiment 17; furthermore, that the maximum postfumigation

temperature for these five experiments is 80° F., a maximum only a few degrees higher than the limit of optimum temperatures established for field fumigation. On the other hand, in the set of experiments (1, 12, 14, 15, and 18) which shows a difference in injury between plants submitted to high and those submitted to low postfumigation temperatures, the range is from a minimum of 23° in experiment 18 to a maximum of 34° in experiment 14. In short, the minimum range in the last set of experiments is 7° higher than the maximum range in the first set which developed no difference of injury; furthermore, the maximum postfumigation temperatures are higher, ranging from 86° to 90° F., except in experiments 14 and 18, in which they are 80° and 79° F. respectively. Another consideration of special importance is the temperature of fumigation, which in the first set of experiments ranged from 60° to 69° F., whereas in three of the five experiments of the set which developed differences in injury the fumigation temperature ranged from 85° to 92° F. Two of the experiments in this last set, namely, 1 and 12, were performed at temperatures of 60° and 64° F. In these two experiments, however, the postfumigation temperatures were very high, 86° and 90° F., and the range between the cold and hot postfumigation temperatures was from 26° to 30°.

The general conclusion to be drawn from these experiments is that the postfumigation temperature exerts an influence on the degree of injury, especially at temperatures of 80° F. or above. The effect of such high temperatures is modified by the temperature of fumigation; for instance, a high postfumigation temperature preceded by a high fumigation temperature is more destructive to plant tissue than a high postfumigation temperature preceded by a low fumigation temperature. In fact, as is well shown in experiments 10 and 15, it is possible to subject plants treated at such low temperatures as 60° to 65° F. to moderately high postfumigation temperatures (79° and 80° F.) without any more injury than at the lower temperatures of 64° or 65° F. The postfumigation temperature of shade or darkness is so closely related to the actual fumigation temperature in modifying plant injury that it is important to take cognizance of each in plant treatment. The influence of temperature on plants subjected to sunshine following treatment has been discussed under the heading "Sunshine." To avoid injury, or at least to reduce the possibility of damage to the lowest degree, the data presented in this paper appear to indicate that after fumigation plants should be placed at temperatures below 80° F. The exact number of degrees the optimum falls below 80° will depend on the prefumigation and fumigation temperatures. When these are ideal the maximum optimum apparently approximates 80° F., but if they are not the optimum is lowered a few degrees.

THE INFLUENCE OF SUNSHINE AT VARYING PERIODS AFTER FUMIGATION.

While experiments 10 to 19 clearly demonstrate the influence of sunshine on plants exposed immediately after fumigation, the following four experiments set forth the effect of this factor where plants are placed in the sunshine four hours or more after treatment.

EXPERIMENT 20.

Condition during fumigation, shade, 62°–65° F.
Condition before fumigation, shade, 66° F.
Dosage, 1 ounce NaCN.
Date, September 21, 1915, 8–8.45 a. m.
Plants in each test, 3; total, 21.

Results.

Condition after fumigation.						
Shade, 79° F.[1]	Shade, 90° F.[2]	Sun, 76° F., exposed immediately.	Sun, 79° F., exposed after 30 minutes.[3]	Sun, 80° F., exposed after 1 hour.[3]	Sun, 84° F., exposed after 2 hours.[3]	Sun, 88° F., exposed after 3 hours.[3]
2	2	5	4	4	3	2

[1] Equal to sun temperature throughout the day.
[2] Temperature held at 85°–91° F. all day.
[3] Plants removed from fumigatorium to shade (temperature approximately 70° F.) until placed in sunshine. Maximum sun temperature 94° F. at 1 p. m.

EXPERIMENT 21.

Condition during fumigation, dark, 58°–60° F.
Condition before fumigation, shade 60° F.
Dosage, 1½ ounces KCN.
Date, March 21, 1915, 8–9 a. m.
Plants in each test, 3; total, 27.
Remarks: Plants were in a somewhat resistant condition.

Results.

Condition after fumigation.								
Shade, 64° F.[1]	Shade, 90°–97° F.[2]	Sun, 77° F., exposed at once.[3]	Sun, 77° F., exposed after 5 minutes.[3]	Sun, 77° F., exposed after 15 minutes.[3]	Sun, 79° F., exposed after 30 minutes.[3]	Sun, 79° F., exposed after 1 hour.[3]	Sun, 82° F., exposed after 2 hours.[3]	Sun, 84° F., exposed after 4 hours.[3]
1	4	4	4	4	4	4	1	1

[1] Temperature 64°–70° F. all day.
[2] Temperature fluctuated 90°–97° F. all day.
[3] Plants held in shade at 61°–62° F. between time of removal from fumigatorium and placement in sunshine. Maximum sun temperature 85° F. at 1 p. m.

EXPERIMENT 22.

Condition during fumigation, shade, 58° F.
Condition before fumigation, shade, 59° F.
Dosage, 1¼ ounces KCN.
Date, March 30, 1916, 8.15–9.05 a. m.
Plants in each test, 3; total, 18.
Remarks: Plants in a slightly resistant condition. Maximum sun temperature 76° F. Plants were removed from fumigatorium to cool shade for the period elapsing before placement into sunshine.

Results.

Condition after fumigation.					
Shade, 60° F.	Sun, 66° F., exposed at once.	Sun, 67° F., exposed after 30 minutes.	Sun, 68° F., exposed after 1 hour.	Sun, 72° F., exposed after 2 hours.	Sun, 74° F., exposed after 3 hours.
1	4	3	3	3	2

EXPERIMENT 23.

Condition during fumigation, shade, 65° F.
Condition before fumigation, shade, 68° F.
Dosage, 1¼ ounces KCN.
Date, March 30, 1916, 12.03–12.53 p. m.
Plants in each test, 3; total, 18.
Remarks: Plants in a slightly resistant condition. They were removed from fumigatorium to cool shade for period elapsing before placement into sunshine. Maximum sun temperature, 76° F.

Results.

Condition after fumigation.					
Shade, 71° F.	Sun, 76° F., exposed at once.	Sun, 77° F., exposed after 30 minutes.	Sun, 76° F., exposed after 1 hour.	Sun, 74° F., exposed after 2 hours.	Sun, 71° F., exposed after 3 hours.
1	4	3	3	2	1

In each of these four experiments all plants were removed from the fumigatorium immediately after exposure, part being placed at once in the sun while the remainder were held in the shade. Those plants which were exposed to the sunshine at different periods following fumigation were held in the shade at a cool temperature (60° to 70° F.) between the time of their removal from the fumigatorium and placement in the sunshine. Some plants were held continuously in the shade at certain temperatures as a check on the injury attributable to direct sunshine.

It is seen by an examination of experiment 20 that the dosage used merely injured the very tenderest growth where plants were placed

under shade temperatures of 79° and 90° F. immediately after the exposure, although plants exposed to the sunshine (76° F.) at the same time had almost all foliage, both tender and resistant, destroyed. Plants held in the shade for 30 minutes and one hour, respectively, after treatment and then subjected to sunshine at temperatures of 79° and 80° F. were about equally affected and this amounted to having a large part of the old resistant foliage destroyed. The injury, however, was noticeably less than where the plants had been exposed immediately after the treatment. Plants withheld for a period of two hours before placement in the direct sunshine had the tender growth destroyed and a few old leaves slightly affected, while plants held three hours before placement in the sunshine were no more

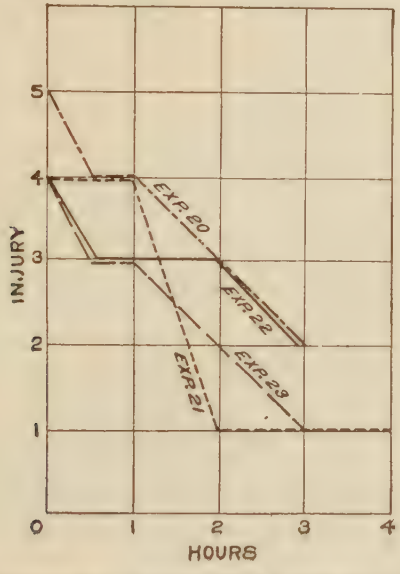


FIG. 1.—Graph showing relation of plant injury to exposure to sunshine at different periods after fumigation.

injured than those placed in the shade, only the tenderest growth being burned in either case.

The results of this experiment are fully corroborated by both experiments 22 and 23, and in part by experiment 21. In number 21, however, although the results agree with those in the other three experiments in showing that sunshine increases the toxic action of hydrocyanic-acid gas to the plant for a period of fully one hour after exposure, it differs somewhat in that the full effect of the sun is shown for one hour after which its influence quickly disappears.

The evidence presented in these four experiments shows that sunshine affects the degree of injury to fumigated citrus trees usually for a period of at least two hours after treatment where dosages equivalent to those used in these experiments are given to growing plants; that the greatest injury follows exposure to sunshine imme-

diately or within a few minutes after the fumigation; that the influence of sunshine which first reaches plants 30 minutes after treatment is practically the same as that of sunshine which first reaches the plants one hour after fumigation, and in all cases is severe; that the effect when plants are withheld for three hours before exposure to sunshine is seldom greater than where they are kept in the shade or in darkness at equal temperatures; in short, that sunshine appears to affect fumigated plants little or not at all at periods exceeding three hours after treatment.

THE EFFECT ON PLANT INJURY OF TEMPERATURE, LIGHT, AND MOISTURE DURING FUMIGATION.

The effect of certain weather conditions during the period when plants are actually exposed to hydrocyanic acid is brought out clearly in experiments 1 to 27.

DARKNESS AND SHADE.

The comparative influence on plant injury of shade to darkness during fumigation is shown by certain experiments, of which numbers 10 and 16 are especially representative. In these experiments are found practically identical prefumigation and postfumigation conditions, and the actual fumigation environments differ only in that No. 10 was performed in the dark while No. 16 was carried on in diffused light. The results of these experiments indicate no difference in degree of injury between plants fumigated in the shade and those fumigated in darkness. Experiments 5 and 17 contain a series of plants which present results corroborating those shown in experiments 10 and 16. A careful comparison of other experiments given in this paper supports the conclusion that citrus plants are as safely fumigated in diffused light as in total darkness.

SUNSHINE.

No experiments were performed in which plants were exposed to sunshine during treatment, but in consideration of the results previously shown where plants exposed to the sunshine immediately after fumigation developed very much more severe injury than others in the shade or dark at equal temperatures, it would appear that at least equally severe injury would develop from sunshine during the actual treatment. Factors which bring about injury from exposure to sunshine after fumigation would appear to be present in at least equal force in exposure to sunshine during actual treatment. Sunshine exposure during actual treatment would be possible only under glass, and in such cases would be accompanied by a temperature greater than that of the outside air.

MOISTURE.

Experiments 4, 6 to 9, and 11, were performed with both dry and wet plants. A comparison of results of these experiments has been presented under the paragraph treating on prefumigation influences. It was found that moisture on plants in prefumigation shade or darkness in no way affects the results where the fumigation is performed in shade or darkness. However, where plants were in sunshine before fumigation it appeared that a wetting with cool water tended to reduce the injury below that normal to dry plants.

TEMPERATURE.

Temperature is a factor of much concern during actual fumigation, and has already been discussed in this paper. Its influence is so modified by the prefumigation and postfumigation temperature and light conditions that it is necessary to pay full attention to these two latter environments in determining the temperature of safety during actual gas exposure. The experiments included in this paper in which plants were at no time exposed to the sunshine, and in which the prefumigation and postfumigation temperatures were within the range of optimum heat conditions, exhibited very little injury where plants were fumigated at temperatures below 80° F. In some experiments in which the temperature of fumigation exceeded 80° the injury appeared to be little if any more severe than at lower temperatures of fumigation, provided the prefumigation and postfumigation temperatures were both low; in other experiments the injury appeared to be greater at the higher temperatures of treatment. When, however, either the prefumigation or more especially the postfumigation temperature was high as well as the actual fumigation temperature the injury was, in general, noticeably more severe than at cooler temperatures. This is well illustrated by a comparison of experiment 1 with either experiment 14 or 15. Unfortunately none of the experiments performed at temperatures exceeding 80° F. were held at a uniform heat throughout the exposure, but the temperature fluctuated at least several degrees after the plants were inclosed in the fumigatorium. This condition introduces a secondary factor which must be taken into consideration in drawing conclusions as to the effect of high temperatures on plant injury.

It appears from a comparative study of the experiments in this paper that severe injury is most noticeable where any two or all three of the fumigation environments, prefumigation, fumigation, and postfumigation, are at high temperatures. In short, if the actual fumigation temperature is high, a minimum of injury is likely to follow if both the other environments are cool. If, however, either the prefumigation or more especially the postfumigation temperature is also high, much more severe injury is likely to result. The evidence

presented in experiments 1 to 27 appears to indicate that the greatest safety demands fumigation at temperatures below 80° F., unless the dosage is weak or the exposure short, and this condition has been corroborated by experiments in orchard treatment.

SUDDEN CHANGES IN TEMPERATURE DURING FUMIGATION.

The following four experiments, when viewed in the light of data given in the preceding experiments, show the effect of a sudden increase in temperature immediately before or during the first few minutes of exposure and followed by a fluctuation of several degrees during the remainder of the treatment. The actual temperature during the gas treatment in the first three experiments was 86° F. or above, while in experiment 27 it was cool, ranging from 61° to 70° F.

EXPERIMENT 24.

Condition during fumigation, dark, 86°–92° F.
Condition before fumigation, dark, 64° F.
Dosage, 1 ounce NaCN.
Date, September 23, 1915, 6.10–6.50 a. m.
Plants in each test, 4; total, 20.
Remarks: Temperature of fumigatorium was raised from 64° to 92° F. immediately before fumigation and held at 86°–92° F. throughout the exposure. Maximum temperature for day, 93° F. at 2 p. m.

Results.

Condition after fumigation.				
Dark, 65° F.	Shade, 67° F.	Dark, 73° F.	Shade, 73° F.	Sun, 73° F.
4	4	4	4	5

EXPERIMENT 25.

Condition during fumigation, shade, 86°–92° F.
Condition before fumigation, dark, 65° F.
Dosage, 1 ounce NaCN.
Date, September 23, 1915, 7.10–7.50 a. m.
Plants in each test, 4; total, 20.
Remarks: Temperature of fumigatorium was raised from 73° to 92° F. immediately before fumigation and held at 86° to 92° F. throughout exposure. Maximum sun temperature for day, 93° F. at 2 p. m.

Results.

Condition after fumigation.				
Dark, 65° F.	Shade, 67° F.	Dark, 75° F.	Shade, 75° F.	Sun, 75° F.
4	4	4	4	5

EXPERIMENT 26.

Condition during fumigation, shade, 86°–91° F.
Dosage, 1½ ounces KCN.
Date, March 18, 1915, 2.05–3.05 p. m.
Plants in each test, 2; total, 20.
Remarks: Temperature of fumigatorium was raised from about 75° to 91° F. immediately before fumigation and maintained at temperature of 86°–91° F. throughout the treatment.

Results.

Condition before fumigation.	Condition after fumigation.				
	Dark, 63° F.	Shade, 65° F.	Dark, 91° F.	Shade, 95° F.	Sun, 74° F.
Dark, 63° F...	4	4	4	4	4
Sun, 77° F...	4	4	4	4	5

EXPERIMENT 27.

Condition during fumigation, shade, 61°–70° F.
Condition before fumigation, shade, 54° F.
Dosage, 1¼ ounces KCN.
Date, March 30, 1916, 7.12–8.02 a. m.
Plants in each test, 6; total, 12.
Remarks: Temperature of fumigatorium was raised from 54° to 70° F. during application of gas and was held at a fluctuating temperature of 61°–70° F. during treatment. Rise in temperature was accomplished in 2 to 4 minutes.

Results.

Condition after fumigation.	
Shade, 57° F.	Sun, 61° F.
5	5

RESULTS.

The experimental evidence presented in this paper indicates that for citrus trees the safest temperatures surrounding fumigation fall below 80° F. Yet in experiment 27, in which the temperature at no time departed from this optimum, the plants were almost defoliated. Experiments 3 and 8 were conducted with equally tender plants, with the same dosage, with the same exposure in one case though a little less in the other, and at comparable prefumigation and post-fumigation temperatures, yet the plants in these two experiments had merely the tender growth burned. A detailed comparison of experiments 3 and 27, however, shows a difference in temperature fluctuations during the exposure to gas, it appearing that experiment 3 was performed at a constant temperature of 57° to 58° F., whereas in

experiment 27 the temperature was suddenly raised during the initial exposure to the gas from 54° to 70° F., a rise of 16°, and fluctuated within the range of 61° to 70° F. during the exposure. It would appear that the shock to the plant resulting from this sudden rise in temperature during the gas exposure accounts for the greatly increased injury in experiment 27 over that in experiment 3 or experiment 8.

The effect of a sudden rise of temperature is also shown in experiments 24, 25, and 26, all of which were performed at temperatures ranging from 86° to 92° F., which are much higher than that of experiment 27. An examination of experiment 25, in which the prefumigation temperature was 65° F. and in which part of the postfumigation conditions were equally favorable, shows that the injury is very severe irrespective of prefumigation or postfumigation environment, in all cases a large proportion of the most resistant leaves being destroyed. The degree of plant injury was much greater than that in experiments 14 and 18, which were performed at equally high temperatures with the same dosage and exposure. In experiment 25 the temperature was quickly raised 19°, from 73° to 92° F., immediately before generating the gas, and was maintained between 86° and 92° F. throughout the treatment. This sudden rise in temperature, supplemented by fluctuation during the exposure, appears to be the cause of abnormally severe plant injury. The results in experiments 24 and 26 are in full accord with that in experiment 25, and corroborate the influence of a sudden rise of temperature immediately before and during the exposure of plants to hydrocyanic-acid gas.

Experiments 14, 15, and 18 also fall within the class of tests in which the temperature was raised during the exposure of plants to the gas. The injury in these experiments is comparatively less than in Nos. 24 to 27.

An examination of the data presented in this paper shows that all experiments performed at high temperatures (above 85° F.) indicate a greater degree of injury, in general, than where plants are treated at cooler temperatures. In each of these experiments the high temperatures were attained by increasing the heat artificially during the gas exposure. These sudden increases in temperature during the fumigation exposure varied from 10° in experiment 14 to a maximum of 28° in experiment 24. Furthermore, after increase to the maximum temperature, fluctuations took place during the actual gas exposure ranging from 2° in experiment 14 to 10° in experiment 27. This condition of sudden rise in temperature, especially when accompanied by wide fluctuation during the exposure, appears to exert a highly injurious influence on the plant. Where the rise of temperature was only 10° to 14°, as in experiments 14 and 18, and was held during the exposure with slight fluctuations of 2° to 4°, the

injury was not especially severe; where, however, the sudden increase was over a wider range, as in experiments 24 to 27, of from 16° to 28° and accompanied by fluctuation in temperature of 5° to 10°, the injury was most severe.

These data are of importance in showing that sudden and wide fluctuations of temperature during the gas exposure should be avoided where possible. Such fluctuations appear to be damaging to plants even where the ranges of temperatures of exposure fall below 70° F., which is considered within the range of optimum for field fumigation.

GENERAL DISCUSSION OF FACTORS WHICH INFLUENCE FUMIGATION INJURY.

Evidence has been presented in the foregoing experiments bearing on the relation of darkness, diffused light, sunshine, temperature, and moisture to foliage injury during the fumigation of citrus trees. Abundant additional data have accumulated during field and laboratory experiments to offer further corroboration of the deductions made from these experiments. The effect of hydrocyanic acid on fruit was not taken up in connection with this series of laboratory experiments, but a very large amount of data on this subject has been taken during field experimentation.

In the fumigation of citrus trees injury to fruit and injury to foliage should be considered separately. The fruit has been observed to be severely injured without the foliage being burned in the least, while on the other hand trees have been noted as defoliated although the fruit was entirely uninjured. Several different types of injury are presented in the fruit and foliage of fumigated citrus trees. These types, though somewhat related in the case of either the fruit or the foliage, are sufficiently distinct to be easily detected.

Foliage injury is properly characterized by discoloration or burning, and is usually accompanied by the shedding of leaves which vary in appearance from those completely burned to others free from defacement of tissue. The tender expanding leaves of very tender succulent stems usually show the first signs of fumigation injury, and this is not localized at any particular place, but sometimes occurs at the edge and sometimes in the body of the leaf. These affected areas are frequently confined to one surface of the leaf though more commonly the injury is equally apparent on both surfaces. As the degree of injury increases the entire tender tips are affected, this at first being evidenced by wilting and finally by death. The length of time following fumigation before tip injury appears depends upon the tenderness of the tip, the concentration of the gas, and such factors as temperature and sunshine conditions surrounding the fumigation. The tender foliage of plants placed in bright sunshine immediately after treatment with a strong dosage may start wilting or dis-

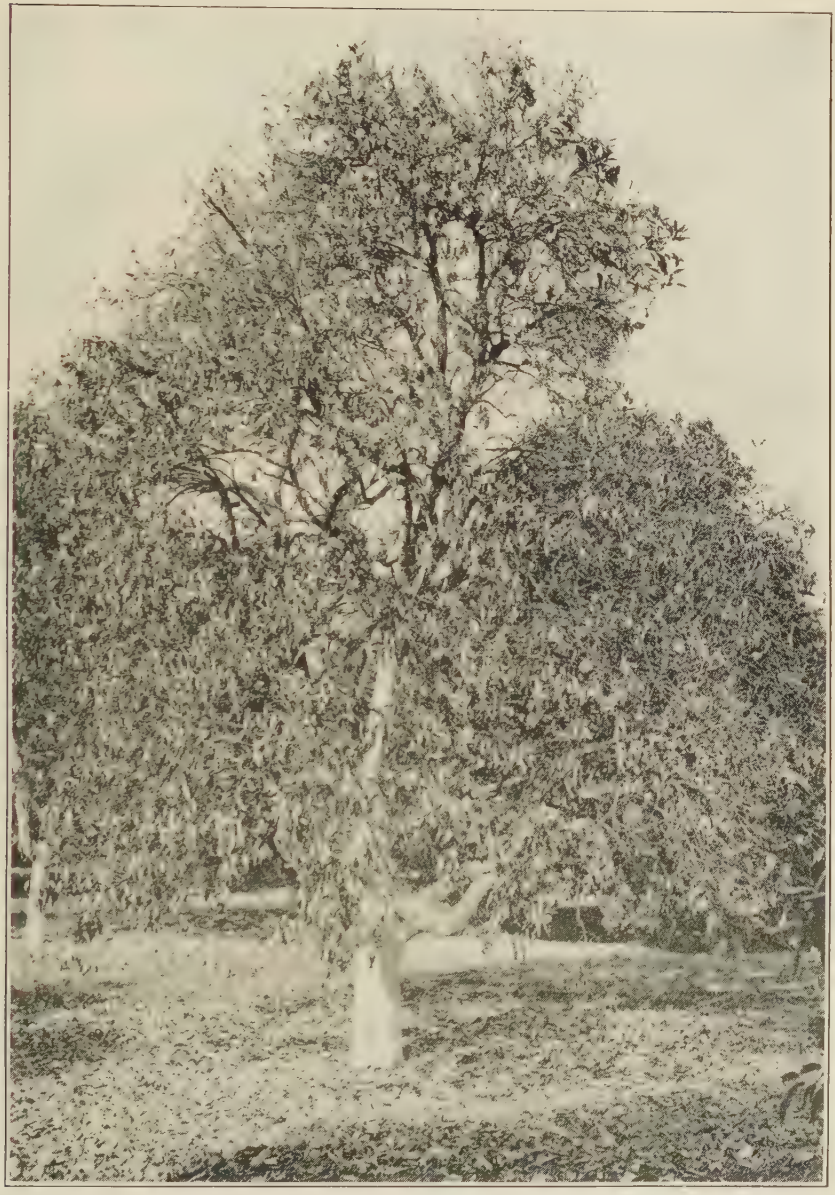
coloration within 2 to 3 hours after the exposure. However, like plants fumigated under like conditions but placed afterwards in the shade or darkness at a cool temperature might not show injury for at least a half day. As a general rule, evidence of injury to active citrus trees unexposed to the direct sunshine for at least several hours after the treatment develops within 24 hours, though the severity of injury may not become fully apparent for 2 or 3 days. Where plants are hardened or dormant at time of fumigation a much longer period is covered before the effects of treatment are definitely exhibited.

Burning of the tender, fully expanded leaves in which the cuticular layer has not yet become fully matured requires a slightly stronger gas than to produce tip injury. As the expanded leaf matures greater resistance to the gas develops. The injury to leaves as observable by defaced tissue may be confined to small distinct areas, sometimes in the case of very tender growth not larger than the head of a pin, or in other cases may include the whole of a leaf. Severely injured leaves drop within a few days to several weeks after treatment, but the shedding of foliage having little or no defacement of tissue is indeterminable because such foliage, especially in the case of mature leaves, might be and apparently is greatly affected physiologically even when little or no superficial evidence is presented previous to the actual abscission. The abscission usually occurs at the base of the blade (Pl. IV, B, *b*) rather than the base of the petiole, but later this also falls.

In any examination into the causes producing plant injury from fumigation with hydrocyanic-acid gas at least four distinct conditions, each of which contributes toward modifying the result, must be considered. These are: (1) The concentration of the gas; (2) the length of exposure; (3) the physiological condition of the plant; (4) atmospheric conditions.

THE CONCENTRATION OF THE GAS.

The modifying influence of gas concentration on plant injury has already been briefly mentioned in this paper. It has been found in experimental work that under the most favorable conditions of treatment fully one-half ounce of high-grade sodium cyanid to 100 cubic feet of space in an air-tight fumigatorium is required to produce injury to normal healthy citrus plants, and dosages in excess of this amount were used in experiments 1 to 27. In orchard work fruit or foliage injury seldom results unless upward of 50 per cent strength of the full dosage schedule recommended by this department and followed in commercial fumigation in California is used. As the gas concentration increases above the strength required to produce initial injury the effect on the plant becomes increasingly severe. In extreme cases the entire plant may be killed, but this result with



FUMIGATION OF CITRUS PLANTS WITH HYDROCYANIC ACID.

A Valencia orange tree fumigated six months after the trunk and main branches had been painted with Bordeaux paste. All the foliage was burned and the fruit ultimately dropped.

FUMIGATION OF CITRUS PLANTS WITH HYDROCYANIC ACID.

A, *B*, Fumigation injury to foliage at point of infestation with purple scale (*Lepidosaphes beckii*). The injury appeared most prominent on the side of the leaf opposite the infestation. *A*, Upper side of leaf, showing purple scale. *B*, Lower side of same leaf, showing collapsed tissue opposite scale infestation. *C*, An immature Valencia orange injured by exposure to sunshine following fumigation. The uninjured area was shaded by leaves. *D*, Twig from a fumigated tree, showing how the leaves are abscissed at the base of the blade, leaving the petioles clinging to the tree.

citrus trees is seldom experienced, so extended is the range between initial injury and death.

It has been shown by the author (*21*) that the distribution of gas beneath the tent is modified by the method of application; that in pot-generated gas the greatest concentration is toward the top of the tree, whereas in the case of gas generated from liquid hydrocyanic acid the concentration is greatest toward the bottom of the tree. Correspondingly the injury in the case of pot or machine generated gas is most marked toward the top of citrus trees fumigated after this method; whereas, when liquid hydrocyanic acid is used, the tendency is for greater injury toward the bottom.

THE LENGTH OF EXPOSURE.

Variations in the length of exposure very naturally modify the effect of the gas on the plant, as early pointed out by Woods and Dorsett (*22*), and recently clearly presented by Fernald, Tower, and Hooker (*5*) in experiments with tomatoes and cucumbers. These latter writers performed experiments in which plants were entirely uninjured when exposed to a certain dosage for 10 minutes but when exposed to the same dosage for 2 hours the plants were killed. The writer has performed many similar experiments with citrus trees and reached the conclusion that for these plants very heavy dosages may be safely used with exposure periods up to 20 or 25 minutes' duration, but where the period of exposure approaches or exceeds 40 minutes the injury is decidedly increased.

Whereas short exposures to hydrocyanic acid have very little deleterious effect on plants, a correspondingly less destructive action to insects occurs with short exposures than with long exposures. In the commercial fumigation of citrus trees for scale insects the normal exposure ranges from 40 minutes to 1 hour. Results under shorter exposures with the dosages used have not proved entirely satisfactory from the standpoint of killing the scales. Experiments by the writer have shown that satisfactory results can be secured with shorter exposures if an increased dosage is used. If, however, the exposure with these increased dosages is greatly extended more injury results. Since commercial outfits consist of from 30 to 100 tents, their movements under all conditions within fixed periods of less than 40 minutes is scarcely practicable. At the present time it is not uncommon for large outfits operating on the basis of an hour's exposure to require 1½ hours for shifts or throws with damp tents on large trees. Thus commercial orchard fumigation appears to resolve itself into using dosages which will not injure trees even when the length of exposure slightly exceeds an hour. An outfit consisting of such a few tents that they would be operated unfailingly within short periods could undoubtedly fumigate successfully with greater dosages and shorter exposures than are now common to the practice.

THE PHYSIOLOGICAL CONDITION OF THE PLANT.

The influence of the physiological condition of the plant on injury has until recently received scant attention by writers on fumigation. It is evident that plant injury from hydrocyanic acid is influenced by the chemical condition of the cells at the time of treatment, for otherwise how could the fact, well known to every fumigator, be explained that tender growing citrus plants are less resistant to gas than those in a dormant and hardened condition, as during the winter. This is equally true with the young leaves as with the mature ones, which indicates that in becoming resistant young growth passes some sort of maturation process. In fact it appears that the condition of citrus plants which renders them hardy or resistant to frost injury likewise develops increased resistance to hydrocyanic acid.

Harvey (*8*) has shown that in the case of cabbage the hardening process results in an increase in the glucose and sucrose content over that present in nonhardened plants and quotes Lidforss as authority for the statement that this is a common transformation in plants generally during the cold season. Chemical changes increasing or reducing the percentage of other substances are also shown to be a result of hardening tissues. It is further stated that the hardening of plants which results in an increase in the cell-sap concentration is an accommodation brought about by low temperature. Plants can also be rendered resistant by growth in a dry soil.

Stone (*18*), working with cucumber plants grown under different light and soil-moisture conditions, showed that the development of tissue is influenced by these factors as well as their susceptibility to burning with hydrocyanic acid. The weaker tissue produced by inferior light or excessive moisture was decidedly more injured than that grown under full light conditions or in dry soil.

More recently Clayton (*1*) experimented with tomato plants and similarly observed that resistance to hydrocyanic-acid gas was modified by the conditions under which the plants were grown. Slow-growing plants with a high chlorophyll content per unit area were found to be more resistant to hydrocyanic acid than plants grown rapidly with low chlorophyll content per unit area, and his conclusions that the water supply was the underlying cause of these differences is in full accord with the prior work of Stone. Chemical examination of the two sets of plants gave results in agreement with those of Harvey (*8*) and others for hardened and nonhardened or actively growing plants, that the more resistant forms have greatly increased carbohydrate content, especially of the reducing sugar calculated as dextrose. Experiments conducted by this writer with plants infiltrated with dextrose showed that resistance to hydrocyanic-acid gas was developed by this procedure and the conclusion was reached that glucose in a plant acts as a protective agent against injury by cyanid.

This important conclusion offers a possible explanation of certain features which the writer has observed in connection with orchard fumigation, namely, the greater resistance of the blossom growth than that of the leaf growth appearing at the same time on the same tree; the greater resistance of this first leaf growth in the winter or spring than that which develops during the hot summer months; the greater resistance of the ripening orange than that of immature fruit.

That chemicals in the cell sap other than reducing sugars can modify injury is strikingly brought out in the case of citrus trees sprayed with Bordeaux mixture or where trunks and main branches have been painted with Bordeaux paste a short time before fumigation with heavy dosages. This damage attributable to Bordeaux applications is evidenced by burning of the foliage and fruit. Plate III shows the severity of injury that frequently follows the fumigation of a tree whose branches and trunk were previously Bordeaux painted. Since the foliage and fruit of this tree were not touched by the Bordeaux paste, but only the branches and trunk, it is evident that certain elements of the fungicide must have been taken into the cell sap and transported to the fruit and foliage which was so severely injured. Proof of this contention has been seen in the extraction of traces of copper from the foliage of such treated trees by Mr. H. D. Young,[1] while chemist of the Citrus Experiment Station at Whittier, Calif. It would thus appear probable that the injury, at least in part, was due to reaction of the cyanid gas on the copper for which it has a great affinity.

It has been observed by the writer (*20*) that fruit injury from fumigation often occurs at places of weakness in the epidermis and that such a condition is sometimes the result of insect action. Plate IV, A, shows that insects can likewise influence injury to leaves by feeding. In this particular case it is of great interest to note that the injury is most apparent at the leaf surface opposite to that on which the insects rest.

It has been pointed out by different authors that the moisture conditions surrounding growing plants influence their development and their susceptibility to injury from hydrocyanic-acid gas, those growing under moist conditions being less resistant to gas than those growing under dry; in short, that dry soil induces gas-resistant plants. Studies made by the writer in the case of field-grown citrus trees appear in general to support this theory. A large lemon orchard, through which a deep, narrow swale extended, was fumigated in November, 1918. At the time of treatment the soil in this swale was moist and had been in this condition at least since the previous irrigation six weeks before. The soil on the upper slopes was very dry. The tents were pulled in a straight string which extended down the slope on

[1] From unpublished results.

across the swale and up on the other side. The three or four trees of each row which were in the damp soil of the swale were severely injured, whereas the trees in the dry soil of the upper slope were entirely uninjured. In another case a 16-acre orchard on heavy soil had been abundantly irrigated twice during the month prior to fumigation and was very moist at the time of fumigation. This orchard was severely injured throughout, whereas an adjacent orchard of the same soil type which had been without irrigation for so long that the soil was dry and the foliage of a hardened appearance at the time of treatment showed very little injury to any trees. Many similar instances of greater injury on damp soil have been noted.

The mere wetness of the soil does not in itself offer full explanation of plant injury due to this factor. For instance, the writer has conducted fumigation of orchard trees immediately following a heavy rain with no more injury than to trees in dry soil. Likewise fumigation frequently follows immediately after an irrigation without noticeable damage to the trees. The writer's own observation inclines him to believe that the greater injury to citrus trees in wet soil is induced especially after the plants have been subjected to a very moist condition for a sufficiently long period to set in action forces which change the general metabolism of the plant and result in foliage or fruit so constituted as to be less resistant to hydrocyanic acid. Support to this is presented by the work of Fowler and Lipman (*6*) on the effect of soil moisture on young lemon trees. These writers concluded that soil moisture in excess of the optimum leads to depressed growth, light colored foliage, and general lack of vigor, the visible damage being greater than if the moisture condition is below the optimum. Of further interest is the statement of Pfeffer (*15*) that the supply of water affects the formation of cuticle. Although a dry soil tends to slacken growth and hasten maturity of plants, thereby rendering them more resistant to hydrocyanic acid, it has been observed that protracted situation in soil so deficient in moisture that the plant suffers ultimately leads to a physiologically weakened condition. It has been stated elsewhere in this paper that plants in a state of impaired health are more susceptible to injury than normal healthy plants.

The soil type also appears so to influence the physiological condition of the tree that modified reaction to hydrocyanic acid sometimes occurs. A 30-acre lemon orchard which was fumigated experimentally in 1918 was about equally divided between two distinct soil types, one a loam designated as a "barren" soil, the other black adobe which contained about 10 per cent humus. Injury occurred throughout this orchard but the degree was noticeably greater on the loam than on the black adobe. Other instances of injury due to different soil types have been noted. Groups of trees

whose growth has not kept pace with the rest of an orchard, due possibly to inferior subsoil, to hardpan, gravel, etc., are not uncommon. Trees under such adverse conditions have sometimes been noted to be more adversely affected by fumigation than healthier trees.

The general conclusion to be drawn from this discussion is that plants best resist cyanid gas if in a hardened or dormant condition at the time of fumigation. Hardening is brought about either by cold weather or a dry soil. From the standpoint of the action of cold, plants are most matured or dormant during the winter season and at this time least injury from fumigation is to be expected. Since citrus is mostly grown in countries that practice irrigation, the dryness of the soil can be regulated by regulating irrigation. Therefore, as a general rule, fumigation should precede the run of water rather than follow, as is frequently the practice at the present time.

ATMOSPHERIC AND LIGHT CONDITIONS.

DARKNESS AND DIFFUSED LIGHT.

Experimental evidence presented in this paper has shown that diffused light before, during, or after fumigation in no way modifies the degree of injury to citrus trees. Since the active stomata of citrus plants open during the daytime and for the most part remain closed at night it is evident that the condition of the stomata does not noticeably alter the degree of injury from fumigation. Such a conclusion is not fully in accord with the statement of Clayton that "the stomata seem to be the most important single factor in determining the amount of injury resulting from hydrocyanic acid * * *. Injury closely paralleled the stomatal movement, increasing as the size of stomatal aperture increased."

These differences in results are readily explained in the light of the work of Stone (*18*) and Moore (*11*). The former states that the condition of the stomata does not appear to have anything to do with susceptibility to burning from fumigation but the injury is due rather to the development of the cuticle and texture of the tissue in general; that tender immature tissue is least resistant to fumigation injury. Moore has shown that hydrocyanic acid enters plants to a greater or less extent through the cuticle and that those with thin cuticles are far more severely injured than those with thick, strongly cutinized cuticles. Geranium, Tradescantia, and tomatoes, the plants with which Clayton worked, have very thin cuticles and were injured with a concentration of gas at the rate of approximately $\frac{1}{15}$ ounce of potassium cyanid to 100 cubic feet. The smallest dosage used in the writer's experiments with the thicker and more heavily cutinized citrus plants was 1 ounce of potassium cyanid to 100 cubic feet.

This shows the comparative resistance of the two types of leaves. Mature citrus leaves are so resistant to cyanid that it appears that the concentration needed to produce injury is so great that the gas penetrates the tissues whether the stomata are open or closed, and the amount which enters while the stomata are open over that entering while closed [1] is insufficient to modify to any great extent the degree of injury. Of particular interest in this connection are the observations of Coit and Hodgson (*2*) that early in the life of the leaf the stomata lose their power of opening and closing and remain for the most part practically closed thereafter. On the other hand, such tender plants as Tradescantia react to such small amounts of cyanid that the stomata seem able to exercise an influence on the passage of gas sufficient to modify the effect on the plant.

SUNSHINE.

The earliest fumigation of citrus trees was performed during the daytime and accompanied by much injury. Coquillett (*3*) offered as an explanation of this result that "in the daytime the light and heat decompose the gas," the assumption being that the products of decomposition are more injurious than the hydrocyanic acid gas itself. In an effort to correct the action of sunlight blackened tents were used but without marked success. The final solution was night fumigation. American writers on fumigation who have experimented with sunshine work have been unanimous in proclaiming its impracticability as a general practice.

The results of the many experiments presented in this paper show that sunshine is one of the most important factors influencing injury and that its effects are not confined solely to the period of exposure, but are also exerted immediately before and immediately after the treatment. The postfumigation influence appears to be somewhat greater than the prefumigation influence and its effects are sometimes so injurious as to discolor fruit (Pl. IV, B, *a*) and destroy the foliage of plants which, if protected from the direct sun, would have been but slightly affected (Pl. I, B). This action on the foliage is most conspicuous through burning which, if including the entire petiole as well as the blade, results in the destroyed foliage clinging to the tree until exfoliation takes place by mechanical means. (Pl. II, B.) This postfumigation sunshine influence in such experiments as No. 10, in which plants in the dark were fumigated in the dark and placed in the sunshine with the result of severe injury, would appear to disprove Coquillett's explanation of decomposition of the gas, for in this case the sunshine did not reach the plants until they had been removed from the fumigatorium.

[1] According to MacDougal (*10*) stomata do not close their pores so tightly that some gaseous diffusion may not take place through their diminished opening.

Temperature has a very direct relation to sunshine influence, and the degree of injury appears to be increased or decreased as the temperature of the sunshine is greater or less. Furthermore, where plants are subjected to sunshine immediately before treatment, the actual fumigation and postfumigation temperatures influence the degree of injury. Likewise in the case of plants exposed to sunshine immediately after treatment, the prefumigation and actual fumigation temperatures require consideration. The writer's own experimental evidence shows that the optimum temperatures of fumigation are below 80° F., and that work conducted at higher temperatures is performed with increased risk. The greatest injury follows the subjection of plants to both sunshine and high temperatures both before and after fumigation. The effect of this combination, sunshine and temperature, has long influenced the time of starting orchard work in California. The fumigation season begins in the summer and extends throughout the autumn into the winter. During the warmest weather work is not started until the sun has set, but with the advent of the late autumn and cooler temperatures the first row of trees is sometimes covered before sundown, and in the winter period of dormancy entire rows are treated in the sunlight. During very hot weather, when the atmosphere is clear and dry, injury to the first row fumigated at night and the last in the morning has been of frequent occurrence and in the latter case has been observed to occur even when the tents were removed from the trees before sunrise. Full explanation of this situation is presented in the results of experiments 20 to 23 which show that the postfumigation sunshine influence may extend up to three hours after exposure, although the maximum of influence is confined to the first few minutes after removal from the gas.

In spite of the fact that sunshine has from the first been considered one of the most harmful agents to plants in connection with fumigation, the greater desirability of daylight work has led to continued attempts to substitute day practice for that at night. These efforts to revolutionize accustomed practice usually were made during the winter months, and frequently successfully over short periods if the weather was moderate and the trees well hardened. Sooner or later, however, this attempt to fumigate by day without modification of dosage or exposure was followed by severe tree damage and was promptly discontinued.

It has been explained previously that cyanid injury is modified by the concentration of the gas and by the length of exposure. Therefore it is reasonable to assume that either of these factors can be so reduced as to render fumigation safe on the hottest sunshiny day. Orchard work is performed with a concentrated gas, usually as concentrated as an active tree will stand safely during cool nights. In

the light of the experiments presented in this paper it is to be expected that the use of such dosages during warm sunshine would cause severe injury. Experiment 3 shows that by reducing the strength of the gas the influence of the sunshine is correspondingly reduced. One orchardist known to the writer has practiced daylight fumigation on his small lemon orchard during the growing season for several years, accomplishing his purpose through reduction of both dosage and exposure. He was observed on one occasion to fumigate lemon trees safely at a temperature of 84° to 86° F. by using a dosage calculated as less than one-half the usual dosage, with an exposure of 30 minutes. The effect on the scale was not noted.

Since liquid hydrocyanic acid has come to be used in fumigation, daylight practice is no longer considered a dangerous experiment. During the winter months outfits operate throughout the daytime in bright sunshine, in many cases with complete safety, and under conditions which in the past with pot or machine generated gas were wont to produce severe injury. Outside of possible differences in physical properties of the gas due to the method of generation and application, the one most plausible reason for the increased safety of daylight operation is the difference in diffusion throughout the tree. In pot-generated gas the greatest concentration is toward the tree top, whereas with liquid hydrocyanic acid in warm weather the greatest concentration is toward the bottom of the tree (*21*). The writer has determined by a series of experiments that the temperature of the tented tree rapidly rises on the sunward side after covering and that the greatest increase is toward the top of the tent. In pot-generated gas the maximum gas concentration, maximum heat, and most sudden change of temperature are exerted at the same place, the top of the tree, whereas in trees fumigated with liquid hydrocyanic acid the greatest concentration of gas at the bottom of the tree is at the coolest part of the sunward side of the tree, while at the top or point of maximum temperature the gas is most dilute. A seeming explanation is presented in the comparative appearance of damaged trees under these two methods of gas application. Sunshine-injured trees from pot-generated gas show the greatest damage on the sunward side toward the top; in the case of trees treated with liquid hydrocyanic acid the damage toward the bottom is greatly increased over that as compared with pot-fumigated trees while that toward the top is lessened.

It was stated in a previous paragraph that the open or closed condition of the stomata does not appear to affect the degree of injury to citrus plants in darkness or diffused light before, during, and after fumigation. In the case of plants subjected to sunshine either immediately before or immediately after exposure to cyanid gas, equally conclusive data bearing on this subject have not been developed. Cer-

tain experiments already presented in this paper have shown that plants in a prefumigation and fumigation environment of darkness (indicating closed stomata) were severely injured by placement in sunshine immediately after the exposure, while check plants placed in the shade at an equal temperature were little affected. In these cases the increased damage to the sun-exposed plant was brought about in spite of the fact that the stomata were apparently closed during the fumigation. Furthermore, data have been collected during daylight work, both in the morning and afternoon, showing that trees somewhat protected from the direct sun were little affected by a strength of gas that severely injured trees in the direct sunshine treated at the same time. On the other hand, the increased injury to plants in a prefumigation condition of sunshine, as previously explained, and observation that greater injury is usually apparent during morning orchard fumigation than during that performed late in the afternoon at an equal temperature, might indicate possible stomatal influence when viewed in the light of Lloyd's (*9*) conclusions that the morning sun may hasten stomatal opening, that this opening is at its maximum toward midday, and that closure occurs during the afternoon.

Stone, Moore, and others conclude that a strong concentration of gas tends to close the stomata. This closure of the stomata from fumigation would reduce the rapidity of the escape of gas which remained in the intercellular spaces after treatment and might thereby modify the degree of injury, especially in plants subjected to such adverse conditions as postfumigation sunshine.

The condition of the soil apparently influences cyanid injury from sunshine, as shown in the case of a 10-acre citrus orchard fumigated during a clear hot day in November, 1919. This orchard was so irrigated that the soil nearest the head of the furrows was thoroughly wet to a normal depth, whereas the soil at the lower end of the furrows was for the most part wet only for a few inches at the surface, or sometimes not at all. The trees reflected this lack of required moisture in their general less healthy appearance. The tents were strung in the direction of the irrigation furrows. Severe injury resulted from the fumigation, amounting almost to complete defoliation on the sunward side of a large part of the trees. This injury was confined almost exclusively to the trees on the dry soil, those on the moist soil being very little affected. The explanation is that the trees which had long suffered from lack of moisture were in a weakened condition at the time of fumigation, whereas the others were not.

TEMPERATURE.

It has been clearly shown by the experimental evidence presented in this paper that temperature exerts one of the most important modifying influences on injury from fumigation. Furthermore, not

only must the temperature of treatment be considered, but also the temperature surrounding plants after exposure and to a much less extent that before exposure. It has been shown that high temperatures are more injurious than low, and in the case of each of the three fumigation environments, the prefumigation, actual fumigation, and postfumigation, the maximum optimum fell below 80° F. Exactly how much this maximum for any particular environment fell below 80° F. depended on the temperature of the other two; when any two were low the maximum optimum for the third approximated 80°; when they were high, however, the maximum for the third was a few degrees less than 80°. In one case it did not exceed 75°. These conclusions differ very little from the writer's experience in orchard fumigation in southern California, for which 70° is held as the maximum when a heavy dosage is used. This same maximum is recommended by Sasscer and Borden (*16*) for greenhouse plants. An interesting relation apparently exists between the maximum optimum temperature for fumigation and the activity of plants, for MacDougal (*10*) states that temperature is one of the most widely interlocking factors concerned in the activity of protoplasm, and that the temperature of greatest activity in seed plants varies from 80° to 100° F. The experimental work presented in this paper shows increasing fumigation injury as the temperature of 80° is approached or exceeded, which corresponds with the degree at which greatest protoplasmic activity commences.

It is possible to conduct fumigation at temperatures of 80° F. or above without serious injury provided the prefumigation and postfumigation conditions are ideal. A high postfumigation temperature increases the probability of damage, and especially is this true if the fumigation temperature is also above the optimum. The greatest damage follows when all three temperatures surrounding the treatment are high. A prefumigation temperature in shade and darkness, even up to 100° F., appears to alter the results very little unless the fumigation or postfumigation temperature is also high, in which case the high prefumigation temperatures are more injurious than the low. The temperature of 55° F. was the minimum at which experimental work was conducted. The little injury evidenced at this temperature showed it to be within the range of the optimum. In field work it has been stated by the writer (*19*) that operations are safe as low as 38° F., although fumigation below this point is not advocated.

In experiments 24 to 27 it was shown that a sudden increase in temperature immediately preceding or during the first few minutes of exposure produces very severe injury, especially if followed by sharp fluctuations of temperature. This factor offers a partial explanation for the severe injury in sunshine fumigation on the sunward side of the tree, especially toward the top, and also presents a

reason for the less amount of injury in daylight fumigation with liquid hydrocyanic acid. This is shown by Table III, in which are presented data giving the increase in temperature at different parts of a 12-foot tree covered with a canvas tent, December 17, 1919.

TABLE III.—*Rise in temperature at different points within a tented citrus tree in the sunshine at varying periods following the covering. Thermometers placed from 6 to 10 inches from the canvas.*

Minutes after start.	Rise in temperature.[a]		
	Sunward side, 11 feet altitude.	Sunward side, 4 feet altitude.	Shade side, 4 feet altitude.
5	8	3	2
10	16	9	3
15	22	12	5
20	26	12	6

[a] Sun temperature at start, 75° F.; shade temperature, 69° F. Time, 10.43 a. m.

It is shown in this table that an increase of 26° occurred toward the top of the tent on the sunward side within 20 minutes after covering, whereas at the same time on the same side 4 feet from the ground the increase was only 12° and on the shaded side of the tree at the same height only 6°. Injury in daylight work has been observed to be proportionately greater at these different points in the case of pot-generated gas. The lower part of the shaded side of the tree, at which the temperature increase is very slight, is seldom injured even when very severe burning takes place on the sunward side of the tree.

The effect of the temperature is least felt in the case of thoroughly hardened trees. In fact, the extent to which sunshine fumigation can be practiced during the winter period is attributable largely to the extent of this hardened or dormant condition of the trees. This condition also offers an explanation for the safety of fumigation at very low temperatures, sometimes at the freezing point, whereas at other times, especially in the early fall, while trees are active, severe injury takes place at several degrees above the freezing point. In the Tulare County citrus belt of California the writer has noted night fumigation, with heavy dosages, carried on during the summer at temperatures as high as 85° F. without apparent injury to the plants. Fumigation in the coast region of southern California at such high temperatures would produce severe injury. He believes that this greater safety in the northern citrus region is due largely to the more resistant condition of the plants brought about by the very hot, arid climate during the summer. Duggar (*4*) states that green leaves exposed to sunlight show a temperature from 2° or 3° to 15° higher than the air, and according to MacDougal (*10*) the maximum temperature of higher plants varies from 100° to 115° F. At or above the maximum

protoplasm passes into a state of immobility. Since the maximum daily temperature of the Tulare citrus belt during the summer frequently exceeds 100° F., the mean maximum for the hottest months seldom falling more than 1° to 3° below this temperature, a reason for reduced activity is presented.[2] This condition is doubtless promoted by the usual practice of withholding irrigation until after fumigation. In the more equable, damper climate of the coastal region, where the temperature very seldom attains a maximum of 100° F., but rather approaches the optimum for protoplasmic activity, dormancy during the summer is less noticeable and the physiologically active plants are more subject to fumigation injury.

MOISTURE.

Moisture, even when present in excessive amounts, appears to have no influence on injury to citrus trees either before, during, or after the treatment, under conditions of shade or darkness, and this conclusion agrees with the work of Gossard (*7*), Morrill (*13*), and others. Under conditions of exposure to hot sunshine before fumigation the application of cool water appears to reduce the degree of injury slightly. These results on the relation of moisture to the fumigation of citrus trees do not necessarily apply to tender greenhouse plants, for moisture on such plants with thin cuticles has been shown by various authors (*11*, *18*) to produce increased injury. Clayton (*1*), however, in a recent paper states that some species are made more susceptible to injury by wetting the leaves while other species are not visibly affected. He places the tomato in the latter class although Moore found that wetting tomatoes as well as various other plants with thin cuticle increased their susceptibility to injury.

The influence of soil moisture has been referred to in previous discussions and may be passed with the statement that soil moisture in sufficient quantity to make plants physiologically very active and tender renders plants more susceptible to fumigation injury than where present only in such quantities as place the plants in a resistant or hardened condition.

Hydrocyanic-acid gas has a great affinity for water, and under conditions of excessive moisture sufficient gas might be absorbed to so materially reduce the concentration that less injury would be produced than otherwise, and, furthermore, its insecticidal value would be lessened. Where fumigation is conducted in gas-tight containers this condition can not be ignored, and the necessity of attention thereto has been clearly shown by Penny (*14*), and Sasscer and Borden (*16*). In orchard work under cloth tents the absorption of gas by moisture is offset by the greater gas-holding properties of the moist canvas.

[2] Taken from published records of the U. S. Weather Bureau, which are lower than orchard sunshine temperatures.

SUMMARY.

(1) It is necessary to consider the prefumigation and postfumigation environments of fumigated plants as well as that during the actual treatment.

(2) Sunshine is the chief prefumigation factor that increases injury and this influence is greater at high temperatures than at low. Under darkness or diffused light, temperatures upward to at least 100° F. do not appear to increase injury unless the fumigation or postfumigation temperatures exceed 80° F.

(3) The environment after fumigation approximates in importance that during the actual treatment. Of the postfumigation factors both sunshine and temperature modify the degree of injury. Sunshine, the more important, is most destructive to plants exposed immediately after fumigation, but affects them deleteriously at least two hours after the treatment. Temperatures of 80° F. or above injure plants more severely than lower temperatures.

(4) The fumigation of citrus plants is most safely performed at temperatures below 80° F.

(5) Diffused light before, during, or after fumigation exerts no more deleterious influence than darkness.

(6) Moisture on citrus plants does not increase the degree of injury. An application of cool water to plants in hot sunshine immediately prior to fumigation appears to reduce slightly the effect of the gas.

(7) Sudden changes of temperature over a wide range during exposure to hydrocyanic-acid gas tend greatly to increase plant injury.

(8) The optimum environment for safety to plants is diffused light or darkness at uniform temperatures below 80° F. before, during, and after the fumigation. The lowest temperature tried, 55° F., was within the range of the optimum.

(9) Fumigation at temperatures upward of 80° F. is safest under cool prefumigation and postfumigation environments. The maximum of injury follows high temperatures for all three environments.

(10) The physical and chemical conditions of the soil influence injury from fumigation. Trees in a wet soil tend to be more severely injured than healthy trees in a dry soil. However, trees in soils deficient in moisture for such protracted periods as to be severely weakened are more susceptible to injury than if grown under optimum moisture conditions. Irrigation should follow fumigation, not precede it.

(11) The physiological condition of plants is one of the most important factors regulating fumigation damage. A condition akin to hardiness appears to be the optimum for gas resistance and is brought about by dryness of the soil, cold weather, and possibly by continued very hot dry weather which exceeds the optimum for the plant.

(12) Sunshine fumigation can be conducted with safety by proper regulation of the dosage and length of exposure.

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